Adopting an exercise program for electronics engineering education utilising remote laboratories for the age of MOOC

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***Abstract*—This paper describes a complete exercise program in an analogue electronics module in engineering education, where remote laboratories are used as an integral part of the exercise program, facilitating also off-campus students. The paper describe how the exercise program and the laboratory assignments aides the students in fulfilling the learning objectives of the module. The creation of a link between the theory learned from the textbook and what is happening in a real world circuit is considered vital to electrical engineering education, and the paper will describe how remote laboratories allow on- as well as off-campus students to take part in this training. A laboratory assignment should have a reasonable level of quality in order to have any meaning for the students. The introduction of remote laboratories in MOOCs, requires the remote laboratory installation to handle a large number of simultaneous users, and introduces several other new challenges that the universities needs to deal with. These include finding a solution to the problem of tutoring students when working on the laboratory assignments, in the remote laboratory environment. The authors has performed several surveys and statistical analysis of the grades among the students at their university, and the findings confirm in all aspects that the presented way of using remote laboratory does have a positive effect on the students' achievements, measured by their knowledge, skills and competencies, as well as their self-evaluation. A discussion of how skills acquired through hands-on experiences can be achieved is included in the paper.**

***Index Terms*—Remote laboratory; exercise program; analogue electronics; engineering education.**

I. Introduction

Nowadays, remote laboratories are used extensively at universities around the world, especially in engineering education. This is natural because the combination of staff at these institutions often have the necessary skills, knowledge and resources to create such systems – from a *technical* perspective. Although the staff has the pedagogical skills necessary to deliver contents and training in a normal classroom and hands-on laboratory setting, the pedagogical foundation for how to deliver contents and training through a remote laboratory environment is often not clear. Some authors [1] focus on mimicking the real-world laboratory instruments as much as possible while the authors of this paper focus on a simplified user interface [2]. This topic is further discussed in [3]. An overview of the use of remote laboratories can be found in [4]. Although economy can be a motivational factor for introducing remote laboratories, the main point in this paper is the pedagogical aspect, and to maintain the quality of the service in terms of the students attaining the learning objectives of the module. This requires the design of the remote laboratory to be close connected to the curriculum of the actual module. The next section gives an overview of the curriculum of an analog electronics module, which is used as an example in this paper. This is a short version of [5].

A. Curriculum overview

The learning objectives of the analogue electronics module can be divided into several parts, depending on how the students receive training in the different skills, how the learning content is delivered, and how the students develop their competencies. The basis of the module is the theoretical knowledge the students learn in class, ranging from the physical description of semi-conductors, to how more complex circuits such as the multistage amplifiers, filters and oscillators work. Then there are several skills that the students are required to master at the end of the module. These include doing calculations on circuits, reading schematics, setting up circuits on a breadboard, and troubleshooting. When combining these two, the students should develop general competencies in analogue electronics, which include designing simple analogue circuits, and to analyze working and faulty circuits. In order to achieve this, the students must create a link between what they learned from theory in class, and what is actually happening in the circuits they set up in the laboratory. The authors consider this competence to be essential to what engineers must have in place, before leaving the university. The authors also discovered that many students struggle with attaining this goal, as reported in [5] and [7], where a suggested solution to this challenge is presented in the next subsection.

B. Overview of the exercise program

The exercise program consists of different activities the students has to participate in and complete. The complete exercise program will give the students adequate training in each of the learning objectives of the module. This program is further described in [5], and a short version is repeated here for the completeness of this paper.

1) Lectures: The lectures form the basis for the module, with intention of giving the students a more in-depth explanation of the theory and other topics covered by the textbook. The lectures are not mandatory, but the vast majority of the students choose to participate here.

2) Problem solving: The problem solving gives the students training in doing calculations on analogue circuits, but is also part of the foundation for understanding the behaviour of analogue circuits. The exercises are often mixed with the lectures, in order to give the students training on what they learned of theory immediately before.

3) Simulations: Where the problem solving gives the students training in discovering the momentary, steady-state values of voltages and currents in an analogue circuit, the simulation training allows them to do the same analysis in a dynamic context, where also the ac and dc values are separated to give further insight into the "dark matter" of small signal analogue circuit behaviour.

4) Hands-on laboratory: In this part of the exercise program, the students are normally given a schematic, and are supposed to set up the circuit on a breadboard and do measurements on the circuit. The measurements are then compared with calculations and possibly simulations in order for them to compare the ideal world with the practical world. Then they will do some alterations to the circuit, some more measurements to see what effect certain changes in the circuit has on the circuit's behaviour. A report is then produced by the students, which has to be handed in to the tutor/supervisor.

5) Remote laboratory: Similar to the hands-on laboratory exercise, the remote laboratory allows the students to observe and analyse the behaviour of an analogue circuit. However, instead of the manual work of putting wires and components into a breadboard, connecting and fiddling with power supplies, oscilloscopes and multimeters, a graphical user interface can be accessed through any major web-browser, where the user is presented with a circuit diagram, where component values, and topology of the circuit can be altered as the user chooses. The experiment can then be run at the click of a button, and the results are presented for the user in the same user interface immediately after. The user interface is accessible through most major web-browsers, on most platforms, including smart phones as shown in figure 1 and 2. An key feature of this particular user interface is the low entry level, focusing as much cognitive resources of the user as possible on the task of understanding the behaviour of the circuit, and as little as possible on operating the remote laboratory, resulting in an improved user experience as reported in section III of this paper.

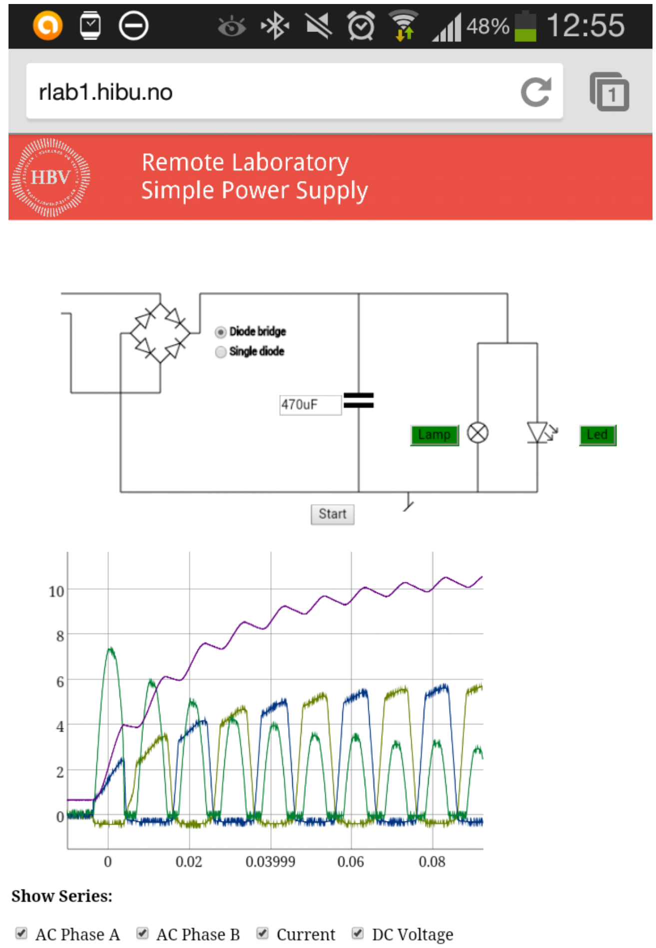

Fig. 1. User interface to a power supply remote laboratory when accessed through a smart phone.

C. Pedagogical basis

The authors started to do trials with remote controlled experiments in an effort to improve the pedagogical quality of the laboratory exercise program. When running laboratory exercises the authors have experienced that the students struggle with fulfilling the learning objectives, specifically the development of the general competence of a deeper understanding for how analogue circuits work, which to a large degree depends on the creation of a link between the theory they learn in class and what they observe during the laboratory exercise. Ideally, the exercise program should give the students adequate training in all the learning objectives as specified in the curricula. In the analogue electronics module, which is used as an example in this paper, it was discovered that there was a significant difference between the amount of training in each of the learning objectives as specified in the curricula, and the amount training the students actually received in each of the objectives.

The authors investigated how the students worked with the laboratory assignment, and identified that the students spent very much time on the things that might go wrong when doing

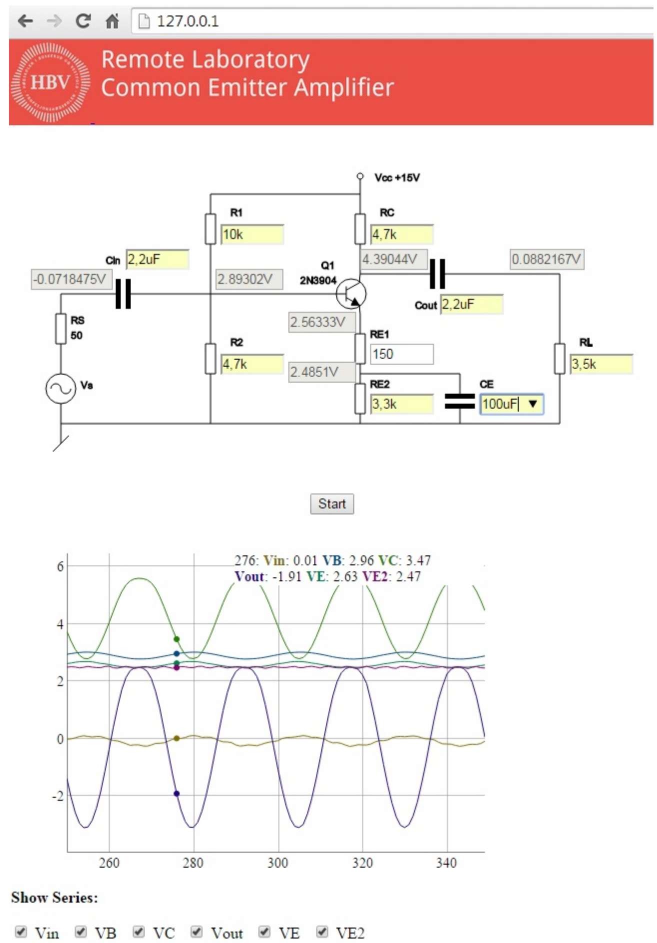

Fig. 2. User interface to a BJT-amplifier remote laboratory when accessed through a web-browser on a computer.

connections on a breadboard: misreading of the schematic, misplacement of components and wires, faulty components or wires, etc. For more complex circuits, an extreme case shown in figure 3 the number of errors seemed to be nearly infinite. A result of this was lengthy and cumbersome troubleshooting. The source of the problem was identified as the relatively large number of training elements present in each activity. The laboratory exercise was performed by reading a schematic of the circuit to be assembled, doing the assembly on a breadboard, connecting signal sources, power supplies and measurement units such as digital voltmeters, amperemeters, oscilloscopes, etc. The students were simply overwhelmed by the number of tasks, for which they had no proper training in, resulting in a sort of cognitive depletion, where the actual understanding were lost.

A suggested solution to this problem was to split the tasks connected to the different learning objectives into several different activities, as described in the previous subsection. Adding the remote laboratory to the exercise program, made it possible to more accurately adjust the amount of training given to the students in each of the learning objectives. Remote

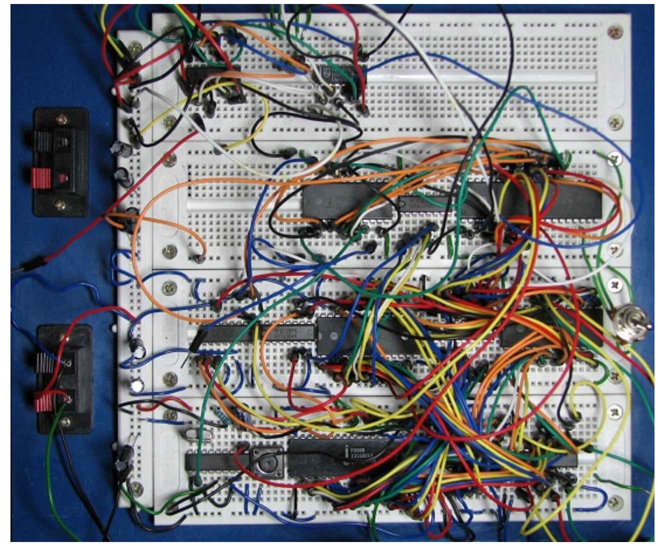

Fig. 3. Complex circuit setup on a breadboard.

laboratories also allows for off-campus students to take part in the exercise program, but this sets demands for the pedagogical foundation of the design of the remote laboratory as explained in [6] and [7].

II. The Remote Laboratory

The motivation for setting up a remote laboratory varies widely, depending on which area of engineering that is to be covered, who the laboratory is intended for and what type of resources that are available for design, implementation and maintenance of the installation. At the authors' university, it is used a low-cost, easy to set up hardware platform, shown in figure 4. This is a combined experiment hardware setup, sampler, signal generator and network interface. To have a complete remote laboratory, only a power supply, the external database server, and possibly an external web server, is required in addition to the hardware shown in the figure. The experiment hardware is implemented using component boards shown in figure 5.

A. Feasibility assessment

Designing and implementing a remote laboratory from scratch is a task that requires a large amount of resources in a number of areas, and is unrealistic for most institutions. There are several parties involved in the design of ready-made open remote laboratory systems. The two most well known systems for implementing the remote laboratory software is the iLab project [8] and the Global Online Laboratory Consortium (GOLC) (http://www.online-lab.org/). The first is a system which consists of lab clients, a service broker and lab servers, as well as a lab resource scheduling service which allows for batch run of pre-configured experiments and for experiments that require interactive control from the user during the experiment. The other is created to facilitate the creation and distribution of shared remote laboratories.

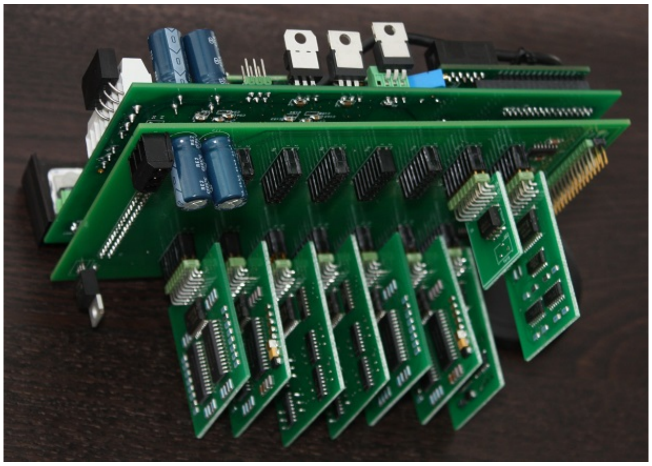

Fig. 4. Main experiment component board with component boards mounted.

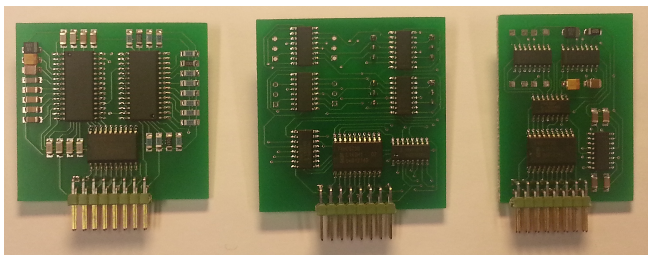

Fig. 5. Electronic reconfigurable component boards.

The organisation carries the statement "The mission of the consortium is the creation of sharable, online experimental environments which increase the educational and scientific value of learning which may not be accessible, scalable or efficient through traditional methods". One of the outcomes of the latter is the Labshare (http://www.labshare.edu.au/) which have developed a resource kit reported on in [9] "to facilitate the engagement of academics". The authors of this paper has presented a simpler software solution in [10], the user interface shown in figure 1. This solution sets very small demands on both hardware and software.

Hence, the design of a remote laboratory is reduced to the job of picking which system is better suited for the job, and possibly adapting it to the specific needs of the university. The choice of software platform should be based on a list of requirements for the remote laboratory, which in turn is based on the learning objectives of the module, the type of laboratory, and other parameters that will affect the choice of software platform.

B. Remote laboratories used in MOOCs

The concept of Massive Open Online Courses (MOOCs), when used in engineering education, has released the need for the Massive Open Online Laboratory (MMOL). There are a number of new challenges that comes into play when using MOOLs, as compared to remote laboratories for a small number of users. Some of these are addressed in Salzmann2016 where the edX platform is used for hosting the MOOC, and this is integrated with a simulation tool and the hardware system, consisting of smart devices integrated as LTI modules. It is then specified three different actions that can be taken to handle the challenge of having a large number of simultaneous users: reducing the time the experiment hardware is occupied by a single user, type of interaction from the user side, and duplication of time critical systems. Further on, the maximum accepted waiting time for the users are measured. The VISIR system[12] is utilised in [13], and there the core problem of using systems such as VISIR is stated as: "The intrinsic limitations of a real laboratory such as VISIR collide with one of the most relevant features that any MOOC should achieve: scalability".

The inherent problem of systems such as VISIR, is that the users gain access to the configuration system – and occupies it – in real-time. This is avoided in systems such as the one reported on in [10], where the configuration data is sent to the experiment hardware *after* the user has finished setting up the experiment in the remote laboratory front-end. The time the user occupies the experiment hardware, can then be measured in fractions of a second, not several minutes, eliminating the waiting time for all practical purposes. In [14] and [15] it is presented a remote laboratory platform that offer relatively small resources to configure new experiments, at a low component cost, and easily scalable accommodate a large number of students.

C. Collaboration in the remote laboratory

As we know from school, young people are not always eager to do difficult things. It has been observed by the authors that utilising elements from a constructivist learning format seems to offer good results. One of the key points of constructivism is to get the students involved in constructing their own learning experience and through this, giving the tutor the role of facilitator and supporter for learning. Experience has shown us that most students will, after some initial misgivings, elect to follow the active learning route and actively be involved in the learning process. In addition to the known pedagogical benefits of constructivist approaches, the rationale for this is that it is simply more enjoyable. The authors would argue that socialisation and collaboration is an important part of this learning.

Social relations between students during learning are therefore an integral part of the authors philosophy for learning. Manninen [17] has shown that the communicative aspect of current multi player games is enabled by a relatively limited set of interaction forms. Even if this research is done in a computer gaming context and not laboratory setting, the finding should be valid.

The limited communication between players in the experiments described by Manninen [17] and the prototypes utilised by the authors is mainly via Internet Relay Chat (IRC). IRC is based around Chat rooms where all users are able to exchange text messages. The setup is such that any user connected to a chat room will get all messages any of the other users transmits. Chat rooms are typically used to cooperate, discuss progress, ask questions in general, and receive help of all other connected users, all in real time. IRC differs from forums in that all is happening in real time and even though a chat server/room may have a log of what has been going on, the purpose is not primarily for this, in contrast to forms where this is the purpose, supporting asynchronous communication. So both methods are text based and supports socialisation between students, but in different forms and time scale, IRC for synchronous quick communication and forms for long term asynchronous communication.

The authors have looked into computer games research and the socialisation that are happening in between players. Studies by Kolo and Baur [18] have shown that many players not only connect to a online game in order to play but also to stay in contact with the fellow players. Many players also connect to fellow players via messaging systems during game play. They engage via their characters in various social interactions from trading or fighting to entertaining other characters. Many players regularly meet the same characters online and address a relatively fixed group of playing partners. This enforces the importance of socialisation in laboratory work in order to encourage the students even more. The aim of a laboratory sessions is to give the students a true understanding of complex theoretical matters and practical realities. Conducted surveys demonstrate that students appreciate the autonomy to learn subjects, feel motivated and consider remote laboratories as a good tool for collaborative learning [19].

D. Automated support system within the remote laboratory

A student doing a laboratory exercise in a traditional setting, i.e. physical laboratory, will typically have immediate access to a supervisor in the laboratory, giving feedback according to the progress of that particular student or group of students. A remote laboratory is an installation that in most cases will be available for the students 24/7, anywhere in the world, and a user of the remote laboratory will probably not have access to a supervisor should they run into problems. This means that the software running the remote laboratory must include a system with automatically generated adaptive feedback, alternatively a system can be envisioned that facilitate transfer of information on each users usage of the remote laboratory and the results obtained from the laboratory experiment for later supervision. Such delayed supervision and support are easier to accomplish in reality though it is not desired and can be seen as a hindrance for learning.

A system is developed that is designed to stop unwanted behaviour where students just utilise a trial and error approach. The system also utilise a batch processing where all requests are completed within seconds, thereby never give the students a feeling of batch processing, but rather giving the students the feeling that they have full control over the experiment all the time. This system has previously been presented in [20].

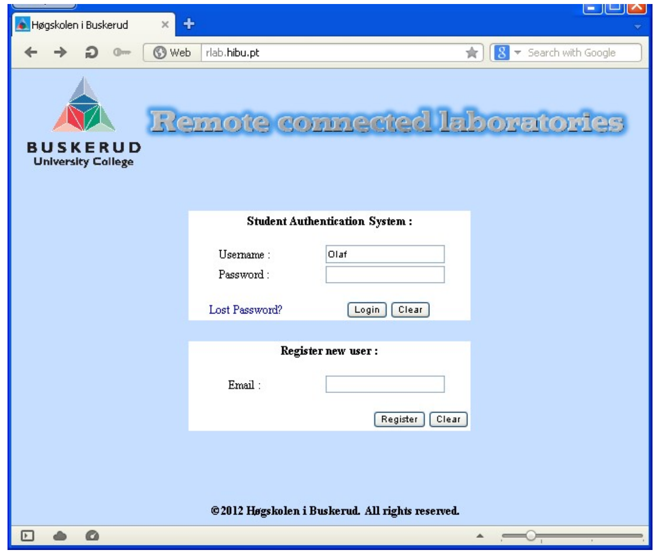

Fig. 6. Web page for user identification via login.

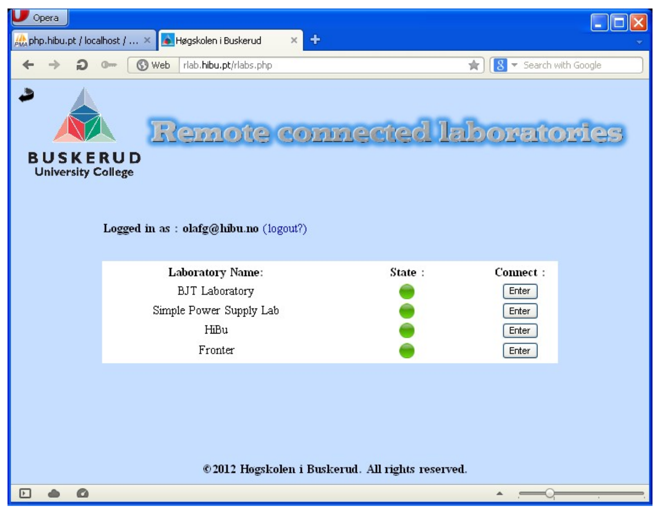

Fig. 7. Web page for listing available experiments the user can access.

The hardware part of the system is identical to the systems described in previous sections. Only the software part differs in order to keep track of each user and their behaviour. When the user enters the frontend of the experiment web server, a login page as shown in figure 6 is used for identifying each user, and is matched with a user in the database system for keeping both configuration and measurement data connected with the user. The web server is also responsible for:

- presenting the screen listing the available experiment to the users, as shown in figure 7.
- acquiring the select parameters for running the experiment from the user.
- presenting the results of an experiment to the user, similar to the figures shown in previous sections.

All this is achieved via what is now a fairly standard web solution with a combination of using both php and java script running on the server and client side. The database is used to store information about users, what experiments that has been run including what parameters was used to set up these experiments, and currently also the results of these experiments. There is a need to set up maintenance tasks that will be in charge of clearing out old data from this database, as the expectations is that the amount of data will quickly be both too great to handle, and will over time be of little interest. The maintenance part is currently a simple and crude mechanism deleting data from the oldest experiments as space is required in the database.

The authors are involved with a long running research project that aims to develop and establish a generic pedagogical model for the use of domain expertise capture in knowledge and skills development, feeding back in to the academic models. The ultimate goal is to produce a model of certifiable knowledge and skills portfolios for individuals, based on automated domain expertise capture, that are widely accepted within industry and academia. Thereby supporting worker mobility, improving high technology industrial performance, and helping to develop the knowledge economy in general.

The project aim to build a model for practical skills development that is accepted in industry could then form the basis for future development and use of such models in Universities and Colleges, potentially with similar materials, bringing the two models more in line. This is done by offering students a portfolio generated from their own work, describing their knowledge and skills, and giving them feedback on areas of strength and weakness could be very motivational. The aim is for the remote laboratories to utilise this portfolio to aid the students working on exercises. A portfolio allows the system to anticipate what aid to provide to the students based on previous work and preferences. This is preferred to the previous system that only reacts to student behaviour after a number of attempts has been made and the in a negative way by blocking a certain behaviours. The implementation of this part of the system are sofar not been been completed.

III. Quality of service of the remote laboratory

The authors of this paper have conducted several surveys on students use of remote laboratories. In [16] it is reported from a survey among students using a remote laboratory for a simple power supply, where the aim was to remove some of the disturbing elements when trying to create the link between theory and practice, as described in section I.C. - “Pedagogical basis”. Not only did the students report that they felt the lab easier to work with, but a small group of students did something that can be described as playing with the system, in the sense that they used the lab for an extensive period of time, trying out different scenarios. This type of behaviour will in the authors opinion contribute a lot to the creation of the link previously mentioned.

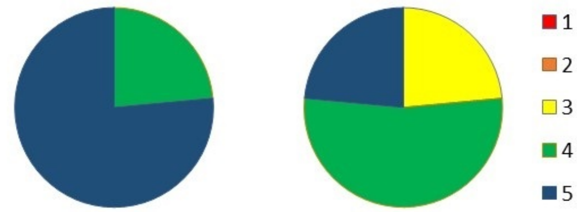

Fig. 8. Student response: Ease of access, and General impression

Fig. 9. Student response: Ease of understanding, and Instructive

In this survey, the students were however quite dissatisfied with software system used to give access to the remote laboratory. The system used LabVIEW remote panels, which require both the users to install extra software on their computers, and also requires certain ports to be opened on firewalls both on their computers and in the routers between the user ant the experiment server. For various reasons, both of these requirements showed to be a significant obstacle, reducing the quality of the service and the user experience were lowered due to this. For this reason, the remote laboratory interface described in the introduction is a converted version of an existing remote laboratory based on LabVIEW remote panels. The software system was converted into a system based on HTML5 as reported on in [21]. The students answered a survey where they rated their experience with the remote laboratory in the context of ease of access, perceived learning outcome, ease of understanding the use of the interface, and a general impression. The results from a 5-point Likert scale survey are shown as pie-charts in figure 8 and 9.

It is important to notice that none of the respondents used the negative part of the Likert scale, and only a fraction of the respondents were neutral in their experience with their use of the remote laboratory interface. It is difficult to conduct a survey or use statistical analysis to show a significant impact on students grades before and after the introduction of the exercise program, as there are too many other factors with unknown impact on their grade, such as variance in the student’s background and knowledge level, but the authors’ general impression is that the students gain a better understanding for the module. This is partly based on their answers in class, and partly on how they manage the hands-on laboratory.

IV. Conclusion

Remote laboratory implementations for a module in analogue electronics is used to show the opportunities and challenges involved in using remote laboratory as part of the exercise program in engineering education in general and in MOOCs in particular. The paper shows that by using low-cost equipment with a low entry-level for the designer, the scalability of the remote laboratory platform park is feasible, and that the quality of service in terms of user experience can be good, even with a large number of simultaneous users. In fact a large number of simultaneous users can improve the user experience by adding functionality such as collaboration between peers, and the paper demonstrates how this can be done. The automated support system necessary for a successful MOOC implementation of a remote laboratory still needs developing, although the basis is presented in this paper.

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